

Mammal extinction by introduced infectious disease on Christmas Island (Indian Ocean): the historical context

Peter T. Green

Department of Botany, La Trobe University, Melbourne, Australia 3086. p.green@latrobe.edu.au

ABSTRACT

Two endemic rat species, *Rattus macleari* and *R. nativitatis*, went extinct on Christmas Island more than a century ago, contributing to an unenviable record of mammal extinctions in Australia. This paper provides the historical context for the extinctions, and shows they were inextricably linked to the expansion of the island's nascent phosphate industry. The endemic rats were killed off by a disease introduced with black rats *R. rattus*, which according to the mining company manager Captain Samuel Vincent, were bought to the island by the *SS Hindustan* that arrived in December 1899. However, historical sources including a photograph held in the National Archives of Australia, together with newspaper shipping intelligence and archival correspondence, all suggest that Captain Vincent was actually referring to the *SS Hindustan* that visited the island in early September 1900. This shortens the period between alien introduction and endemic extinction from five years to four years. At the time, the arrival of black rats was noteworthy not for their impact on the native rats, but because they frustrated attempts at growing fresh food and were implicated in the appalling death toll of Chinese coolies during an outbreak of beriberi. This research corrects and adds to the century-old and widely reported account of these extinctions, and places the introduction of *R. rattus* in a broader historical context.

Key words: biological invasion; Christmas Island; extinction; historical ecology; Maclear's Rat; *Rattus macleari*; *Rattus nativitatus*; *Rattus rattus*; *SS Hindustan*; *SS Hindustan*

<http://dx.doi.org/10.7882/AZ.2013.011>

Introduction

The precise circumstances under which alien species are introduced to novel habitats are usually little known and poorly documented. Obvious exceptions to this would be the deliberate introduction of alien species either for sport (e.g. the European rabbit *Oryctolagus cuniculus* – Myers *et al.* 2003, brown trout *Salmo trutta* – Townsend 1996), acclimatization (Ritvo 2012), botanic garden acquisitions (Hulme 2011) or as biocontrol agents gone wrong (e.g. the cane toad *Bufo marinus* Low 1999), but rarely are the precise circumstances surrounding the accidental introduction of alien species well known and documented. Similar arguments can be made for species extinctions. With few exceptions (e.g. the thylacine *Thylacinus cynocephalus* – Paddle 2000, passenger pigeon *Ectopistes migratorius* – Flannery and Schouten 2001, St Helena Olive *Nesiota elliptica* – Cairns-Wicks 2004, and the Christmas Island Pipistrelle – Lunney *et al.* 2011), most extinctions proceed unheralded and their causes unidentified.

Australia holds the unenviable position as having the world's worst record of mammal extinctions, with almost half of all recorded extinctions in the last 200 years occurring here (Johnson 2007). Three of these, two rats and a bat, have occurred on the Australian Territory of Christmas Island in the north-eastern Indian Ocean. For one of them, the endemic murid rodent *Rattus macleari* (Fig. 1) we know some of the story of its extinction encompassing both the biological invasion that caused it, and the time course of the rapid population crash to extinction early in the 20th century. At the end of the 19th century *Rattus macleari* was abundant all over the

island, and Charles W. Andrews (Fig. 2a), a naturalist who visited the Island for 10 months in 1897/98 described *R. macleari* as “by the far the commonest of the mammals found in the island; in every part I visited, it occurred in swarms. During the day nothing is to be seen of it, but soon after sunset numbers may be seen running about in all directions, and the whole forest is filled with its peculiar querulous squeaking



Figure 1. *Rattus macleari*. This illustration originally appeared as Plate XLII in Part I, Mammalia by Oldfield Thomas, in a Report on a zoological collection made by the officers of the H.M.S. 'Flying-Fish' at Christmas Island, Indian Ocean, communicated by A. Gunther in the Proceedings of the Zoological Society 1887. Accessed 1 February 2013 from <http://commons.wikimedia.org/wiki/File:MusMacleariSmit.jpg>



Figure 2. Charles William Andrews (a), a naturalist from the British Museum (Natural History) who conducted the first comprehensive surveys of the biota and geology of Christmas Island. He described *Rattus macleari* as abundant on his first visit to the Island in 1897-98, and both *R. macleari* and *R. nativitatus* as extinct during his second visit in 1908. Both visits were funded were Sir John Murray (Figs. 6 and 7). Reproduced from Obituary Notices of Fellows Deceased, Charles William Andrews 1866-1924, *Proceedings of the Royal Society of London B* 1926, with permission from the Royal Society. Richard Hanitsch (b) was a German entomologist who served as the Director of the Raffles Museum in Singapore from 1908-1919. Together with Henry Ridley from the Singapore Botanic Gardens, he made an expedition to Christmas Island in 1904 and despite extensive searching (see Green et al. 2010), did not see either of the two species of native rats. Image downloaded from <http://www.rmbs.nus.edu.sg> on 1 February 2013. Herbert Edward Durham (c) arrived on Christmas Island in November 1901 as part of the 'Beriberi Expedition' from the London School of Hygiene and Tropical Medicine. He collected the skins of both *R. macleari* and *R. rattus* upon which Pickering and Norris (1996) and Wyatt et al. (2008) based their work. Genetic analyses of these skins were instrumental in showing that trypanosomiasis introduced by the black rat was the proximate cause of extinction of *R. macleari*. Image V0028694 downloaded from Wellcome Images, the Wellcome Library, London (<http://images.wellcome.ac.uk/indexplus/image/V0028694.html>) on 1 February 2013.

and the noise of frequent fights” (Andrews 1900). The rats were extinct just a few years later. The basic story (Pickering and Norris 1996; Wyatt *et al.* 2008) is that in December 1899 the SS *Hindustan* visited the Island and in doing so inadvertently introduced the black rat *Rattus rattus* in a bale of hay. Neither species could be found by Dr Richard Hanitsch (Fig. 2b), the director of the Raffles Museum in Singapore, during an expedition in September/October 1904 (Hanitsch 1923). He went to the Island “expecting great sport from these creatures”, and had armed himself with “several dozens of traps and had quite made up our minds to substantially reduce the rat population of the island”. Hanitsch explored widely (see Green *et al.* 2010), and his failure to even see these rats suggests very strongly they were already extinct. Andrews (1909) confirmed the extinctions following his second visit to the Island in 1908.

From the outset, it was understood that a blood borne parasite transmitted by fleas from the introduced black rats was implicated in the decline of the native rats (Durham 1908; Andrews 1909). However, the discovery of several skins in museum collections in the 1990s, collected on Christmas Island at the time of the decline, suggested a refinement of the disease hypothesis. These skins were thought to display characters intermediate between *R. rattus* and *R. macleari*, suggesting that population decline caused by disease may have been a significant selective pressure for the endemic rats to hybridize with the *R. rattus*, leading to genetic swamping and eventual extinction (Pickering and Norris 1996). However, hybridization is unlikely given the genetic distance between the species, and re-examination of the putative hybrids confirms they belong to one or the other species (Musser and Carleton 2005). Further, DNA analyses of century-old *R. macleari* museum specimens show no support for the interbreeding hypothesis, but very strong support for the disease hypothesis (Wyatt *et al.* 2008). Thus, we know very precisely the identity of the key invaders – a triumvirate of invasive black rats, their parasitic fleas and trypanosomes, their vector of introduction – the SS *Hindustan*, the place and date of their arrival – Flying Fish Cove, December 1899, and the impact of their invasion – rapid extinction of the endemic rat *R. macleari*, and the coextinction of its endemic tick *Ixodes nitens* (see Mihalca *et al.* 2011). In all likelihood black rats and their pathogens also caused the extinction of the other endemic murid rodent *R. nativitatus*, and possibly played a role in the precipitous decline of probable extinction of the endemic Christmas Island shrew *Crocidura trichura*.

This is one of many examples where the introduction of alien species has been identified as the proximate cause of extinction, but the only case so far for a mammal extinction by introduced disease. The study by Wyatt *et al.* (2008) has already been cited 20 times in the scientific literature (SCOPUS, 1 August 2013), and it has also been widely reported on the internet; a Google search on ‘Wyatt Rattus macleari’ (1 August 2013) gets 40,900 hits, while ‘Hindustan Rattus macleari’ gets 146,000 hits. Further, the story of introduction of *R. rattus* to Christmas Island on board the *Hindustan* is retold in the IUCN Red

List profile for *R. macleari* (Lamoreux 2011). Along with other examples of extinction by epizootic disease (e.g. the chytrid fungus *Batrachochytrium dendrobatidis* and amphibian extinctions, Skerratt *et al.* 2007), the extinction of *Rattus macleari* on Christmas Island is likely to enter the text books as an example of extinction by introduced disease. For these reasons, it is important to ensure that the historical detail surrounding the extinction of this native Australian rat is known as completely and as accurately as possible.

Both Pickering and Norris (1996) and Wyatt *et al.* (2008) cite Durham (1908) as their source for the timing and identity of the ship that brought invasive rats to Christmas Island. Herbert Durham (Fig. 2c) was a bacteriologist, sent to the Island by the London School of Hygiene and Tropical Medicine and funded by the Christmas Island Phosphate Company, to find a solution to the beriberi epidemic that was ravaging the Chinese coolie workforce (Hunt 2011). He arrived on the island in late November 1901 and stayed for several months, and made a second trip commencing March 1903. Durham’s arrival thus postdated the introduction of black rats, and he reported that his original informant was Captain Samuel Vincent, the first manager of the Company. Vincent had arrived on the Island in April 1899, and in 1899/1900 he was one of just four Europeans resident on the Island (Clayton 1901). As manager of a new mining operation in this geographically and socially isolated outpost, he would have been on-the-spot to receive ships when they visited Christmas Island and anchored at the only port, Flying Fish Cove. Durham reported that Captain Vincent told him “that these rats were first introduced to the Island in December 1899 by the SS *Hindustan* in a cargo of hay; they had multiplied to very great numbers at the time of my (Durham’s) visit 1901-1902, but apparently they remained about the settlement.”

In this paper I present new historical information about the identity of the ship referred to by Captain Vincent, and the timing of its arrival. I also explore the possibility that *R. rattus* was introduced to Island earlier than indicated by Captain Vincent, and I use historical shipping records to narrow the most likely period during which this might have occurred. Finally, I present a new time course of events leading up to the extinction of the native rodents. While this work in no way changes the conclusions reached by Wyatt *et al.* (2008) as to the proximate cause of the extinctions, it corrects several historical inaccuracies reported in the story to date and puts the extinction narrative into a broader historical context.

The identity of the ship

According to Captain Vincent, *R. rattus* was introduced to Christmas Island in a cargo of hay by the SS *Hindustan*. The 2421 gross ton SS *Hindustan* (Fig. 3) was built in 1892 by Osbourne, Graham & Co. in the great shipyards at Sunderland, United Kingdom for the businessman H.W. Squance. The following year he formed the Hindustan Steam Shipping Co Ltd to



Figure 3. “Coal loading at The Dyke with Number 12 Crane, Newcastle Harbour, NSW 17 June 1897”. This image was scanned from the original glass negative taken by Ralph Snowball, and is part of the Norm Barney Photographic Collection held by the University of Newcastle, NSW. Under magnification, the letters S_T_A_N are identifiable on the stern, while N_D_U_S_T_A is clear on the bow. Newspaper shipping records place this ship, the SS *Hindustan*, between Philadelphia and Havana in Dec 1899 at the time when it was reported by Durham (1908) to have visited Christmas Island. © All rights reserved by Cultural Collections, University of Newcastle. <http://www.flickr.com/photos/uon/3676991468/sizes/o/in/set-72157622628357892/>

take possession of the vessel, which he sold in 1893 to the Common Bros of Sunderland. Using searchable, digitised newspaper archives from England (*The Times*; GALE database <http://gale.cengage.co.uk/times.aspx/>), Australia (TROVE database, The National Library of Australia <http://trove.nla.gov.au/newspaper>), Singapore (<http://newspapers.nl.sg/>) and the USA (<http://www.fultonhistory.com/Fulton.html>), I have tracked the movements of this ship from the time she left the northern hemisphere and entered the Indian Ocean via South Africa in late 1896, and then in some detail followed her movements through 1897, 1898 and to the end of 1899, when she was supposed to have visited Christmas Island (Table 1). From March 1897 to July 1898 the *Hindustan*, on charter to the Adelaide Steamshipping Company, was mostly engaged in moving grain and coal between Western Australia, South Australia, Victoria and New South Wales. However, she did make two trips to south east Asia, one in December 1897/January 1898, and the other in Jun/July 1898. On the first of these trips she carried a cargo of coal from Newcastle (in New South Wales) to Surabaya on the north coast of Java. It is unclear in which direction she sailed for Java, but given that she sailed south from Newcastle to Melbourne in early December 1897, it would seem she took a southern route via Western Australia. She arrived in back in Fremantle (in southern Western Australia) from Java in late January 1898, where she briefly went aground in the shipping channel.

Christmas Island lies slightly to the west of a direct route from the Sunda Straits to the ports of Fremantle and Albany in south western Australia, and so the *Hindustan* would have passed very close to Christmas Island at least once (on the return leg) and possibly twice (if she sailed outward via the southern route) two years before Captain Vincent's report. On her second trip to Singapore in mid-1898 she sailed from eastern Australia via Fremantle, so again the *Hindustan* would have steamed very close to Christmas Island – in fact, steamers sometimes came within sight of the island to get their bearings (Keyser 1896). Both voyages occurred well before Vincent's report of the *Hindustan* at Christmas Island in December 1899, and it is extremely unlikely that she called in at Christmas Island on either of them – phosphate was not even being mined at the time, and the only people living on the island were Andrew Clunies Ross, his family and several workers, all from the Cocos Keeling Islands further west. They were supplied by the family's sailing vessels, either from the Cocos Keeling Islands or from Batavia (Jakarta), and were not reliant for resupply by commercial vessels. Further, newspaper shipping news makes no mention of the ship calling in at Christmas Island on either voyage, nor are the visits of any large steamships other than those carrying colonial administrators mentioned in their Annual Reports for either 1897 or 1898. On leaving Singapore in July 1898 the *Hindustan* steamed on to Karachi in Pakistan, and then appears to have spent the next two years in the Atlantic and Caribbean. At the time when Captain Vincent reported her at Christmas Island, the *Hindustan* had in fact just arrived in Havana, Cuba, half a world away. Clearly, the SS *Hindustan* could not have been the ship that introduced *R. rattus* to Christmas Island.

A recently discovered photograph in the National Archives of Australia (NAA) clears up this mystery. The NAA holds an extensive collection of material relating to the history of the Island, including many documents and photographs describing the earliest days of settlement and phosphate mining, including the undated photograph in Fig. 4a. It shows a ship moored off the coastal limestone cliff being tended by 10 small barges, operated by Chinese coolies wearing traditional conical hats. Most coolies on the barges appear to be engaged in loading or unloading activities. There are also coolies on deck, and two are suspended on a plank painting the side of the ship. All the activity is being supervised by a European overseer standing aft of the lifeboats, resplendent in tropical whites and pith helmet.

The point of interest lies in the spelling of the ship's name. Whereas Durham (1908) reported a ship called *Hindustan*, the handwritten caption on this photograph clearly reads *Hindoustan* ('SS *Hindoustan* loading 4 hatches'). The name on the bow of the ship is indistinct (Fig. 4b), and the last few letters are obscured completely by what appears to be the ship's anchor. The first few letters are indistinct even under magnification, but are more consistent with the spelling in the caption (*Hindoustan*) rather than with Durham's (1908) report (*Hindustan*).

Table 1. Timelines for the construction, movements, and eventual demise of the steamships *SS Hindustan* and *SS Hindoustan* between Nov 1897 and their demise after 1905. This table was derived from information on The ShipsList website (<http://www.theshipslist.com/>), and from shipping and court records extracted from searchable, digitised archives for newspapers in Australia, Singapore, the United Kingdom and the United States.

Year	Month	SS Hindustan	Year	Month	SS Hindoustan
		Built in 1892 by Osbourne, Graham and Co. at Sunderland, UK for the businessman HW Squance. Launched 7 September 1892, 2420 gross tons. A year later Squance formed the Hindustan Steam Shipping Co. Ltd. to take possession of the vessel, and then sold it to Common Bros. of Sunderland			Built in 1881 by Palmer and Co., Jarrow (Newcastle) for <i>Maurice et Reunion</i> . Launched 23 Nov. 1881, 2895 gross tons.
1897	Nov	23 rd – dept. Newcastle with a cargo of coal for Surabaya (Java), probably via the southern route around Western Australia			
	Nov	26 th – slipped her moorings in the Yarra River (Melbourne) and collided with the <i>Carte Blanche</i>			
1898	Jan	25 th arr: Fremantle from Java. Ran aground in the Fremantle Channel. Departed for Melbourne 27 th .	1898	Jan	21 st sold to Burrell & Son, of Glasgow 22 nd Sailed from Liverpool for Delaware Breakwater
	Feb	4 th arr: Melbourne, then sailed to Sydney/Newcastle.			
	Mar	1 st dept. Sydney carrying 2500 tons of NSW and Victorian wheat for Cape Town, South Africa, via Albany WA.	Mar		8 th Cleared in Savannah to sail for Bremen and Hamburg 29 th arr: Dartmouth from Bremen and Hamburg
			Apr		2 nd arr: Bremerhaven from Savannah
	May	15 th arr: back in Albany, sailed to Newcastle.	May		5 th arr: New York from Hamburg
	Jun	8 th dept. Newcastle for Singapore via Fremantle with 3457 tons of coal	Jun		3 rd arr: Antwerp from New York 18 th sailed from Shields for Sandy Hook (NY)
	Jul	8 th arr: Borneo wharf, Singapore. Dep. 9 th for Karachi (India).			
	Aug	16 th dep. Karachi for South Africa and UK with a cargo of grain	Aug		3 rd Sailed from Quebec for Glasgow 9 th arr: Glasgow
	Sep	22 nd dep. Manchester (UK) for Buenos Aires			
			Nov		22 nd arr: Sandy Hook (NY) from Glasgow and St Johns
1899	Jan	Arr: Buenos Aires	1899	Jan	20 th arr: Sandy Hook (NY) from Shields
	Feb	Dep. London for Sydney			
	May	Arr: back in UK with live stock			
			July		4 th dept. Liverpool, arr: Mobile 25 th
	Sept	Sailed from UK to Delaware, USA			
			Nov		25 th arr: Cape Town from Buenos Aryes
	Dec	Sailed Philadelphia USA to Havana Cuba, involved in a collision with a dredger.			

Year	Month	SS Hindustan	Year	Month	SS Hindoustan
1900			1900	April	At Buenos Aryes
				May	19 th arr. Beira in Mozambique
	Oct	Arr: Queenstown, Cork (Ireland) from Baltimore. The long delay in her return to the UK may have been caused by repairs.		Oct	4 th passed Perim, Straits of Hormuz
	Nov	25 th Expected to arrive Singapore from New York			
				Dec	8 th signaled off Lizard Island (Cornwall) 10 th arr: Liverpool from Memel
1901		Sold to <i>Cia Cantabrica de Nav</i> , Bilbao, and renamed <i>Valmaseda</i>	1901	Mar	3 rd departed Dunkirk
	Nov	8 th arr. St Vincent from La Plata		April	expected Singapore 16 th Sold to Japan, renamed <i>Musashino Maru</i>
			1905		Wrecked on Elliot Islands prior to 6 Feb.
1910	Nov	1 st wrecked at Rio Cana Beach, 80 nautical miles south of Vera Cruz, Mexico on a voyage from Cardiff (Wales), again carrying coal.			

The 2895 gross ton *Hindoustan* was built at Jarrow in 1881 by the famous shipbuilders Palmer and Co., and again, newspaper shipping records permit a fairly comprehensive reconstruction of her movements (Table 1). For several years she made regular runs from London to Marseilles, Mauritius, Reunion and Madagascar, and was sold to the Compagnie Nationale de Navigation in Marseilles in 1886. There are records of the *Hindoustan* at Calcutta, Pondicherry and Singapore in 1886/87, suggesting she spent some time in the Indian Ocean during those years. In October 1887 she was almost destroyed by fire at her home port in Marseilles, but was evidently salvaged and refitted because she is recorded at several Atlantic ports over the next decade, including Lisbon, New York, and Rio de Janeiro. During this time she made at least ten transatlantic voyages carrying Italian migrants from Naples to Ellis Island in New York, but also spent most of 1895 on voyages

between Marseilles, Singapore and Haiphong (Vietnam). After being sold to Burrell & Son of Glasgow in January 1898, she continued making transatlantic voyages for the next twelve months between Glasgow, Liverpool, Delaware, Savannah, New York, Antwerp, Hamburg and Bremen. She departed Liverpool in the UK on 4 July 1899 and arrived in Mobile (Alabama) on 25 July, Cape Town on 25 Nov 1899, and at Beira in Mozambique in May 1900. She was next recorded in October 1900 passing Perim in the Straits of Hormuz, on her way back to the UK via the Suez Canal.

Given the impossibility of the *Hindoustan* being in the Indian Ocean in December 1899, and the caption on the NAA photograph, it is unassailable that it was the *Hindoustan* to which Captain Vincent attributed the introduction of *R. rattus* to Christmas Island. It would appear that in relying on a verbal report from Vincent, Durham assumed the ship's name was spelled the same way as the administrative region of India then under British rule, and frequently referred to in newspapers of the time – a reasonable mistake for a colonial Englishmen.

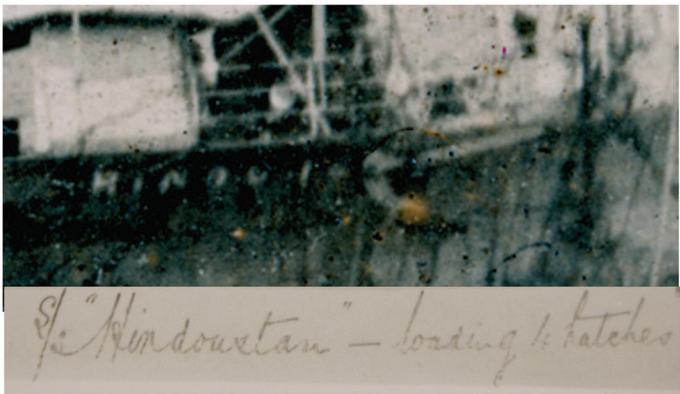


Figure 4. (a) The *SS Hindoustan* moored near Flying Fish Cove, Christmas Island. Undated photograph held by the National Archives of Australia (NAA R32/I6, CIPCI, Barcode 4341008). The caption in the photograph album reads “SS Hindoustan loading 4 hatches”. (b) A high resolution scan of the original photograph, cropped to show just the bow with the ship's name.

Archival evidence for the timing of the *Hindoustan*'s visit

The NAA photograph is undated, which is unfortunate because that would have provided independent confirmation of Captain Vincent's report to Durham for the timing of the *Hindoustan*'s visit to Christmas Island in December 1899. Other documents indicate a different date. The first is the *Annual Report* on Christmas Island for 1900, by the visiting colonial administrator Lewis Clayton (Clayton 1901). In this report he provided a table showing the amount of phosphate shipped from the island, giving the date, numbers of tons, and the destination of fourteen shipments for the previous twelve months. The earliest listed was 15 November 1899, and the last in October 1900; tellingly, there was no shipment listed for December 1899. Second, Clayton reproduced a very similar list in correspondence with his superiors in Singapore detailing a dispute over shipping charges, this time just for shipments made in 1900, and with the names of the ships included (Clayton 1902a). One of these was the SS *Hindoustan* which departed Christmas Island on 3 September 1900, loaded with 3300 tons of phosphate. The corresponding entry in his *Annual Report* for 1900 indicates this shipment was bound for Grabow in Prussia. Newspaper shipping intelligence indicates that the only ship of that exact name operating around this time was a Chilean-registered wooden cargo ship, but that ship was burnt at sea and sank in the Pacific Ocean in March 1900 (*The Argus*, 7 May 1900 pg 5) and so it could not have been the ship to which Clayton was referring. However, the timing and destination of the steamer as reported by Clayton fits very neatly with the newspaper reports for the *Hindoustan* (Table 1) – she was sighted off Perim returning to Europe a month later on 4 October, and she had visited Memel in Prussia before returning to Liverpool on 10 December. It seems almost certain that like Durham, Clayton misspelled the *Hindoustan*'s name. Apparently, this ship gave both of these highly educated colonial Englishman quite some difficulty.

Did the *Hindoustan* visit Christmas Island twice, the first time in December 1899 as reported by Captain Vincent to Durham, or did this ship make just one visit in September 1900, which Vincent later misremembered as December 1899? As pointed out above, Clayton (1900) did not list a phosphate shipment for December 1899. In any case, shipping intelligence makes her presence in the Indian Ocean in December 1899 very unlikely; the *Hindoustan* was at Liverpool on 5 July 1899, Mobile on 25 July, then in Buenos Aires (date unknown), Cape Town on 25 November 1899, then back in Buenos Aires in April 1900, and at Beira in Mozambique on 19 May 1900 (Table 1). Thus, shipping records suggest the *Hindoustan* was still in the Atlantic Ocean in December 1899. It seems that in the retelling to Durham, Vincent simply muddled his dates, and so Clayton's report on the shipping dispute firmly dates the NAA photograph of the *Hindoustan* at Christmas Island (Fig. 1b) as early September 1900.

The timing of the introduction of *R. rattus* to Christmas Island according to Captain Vincent

In addition to his report to Durham (1908), Captain Vincent also reported a second, much later date for the introduction of *R. rattus* to Christmas Island. In a letter published in *The Straits Times* on 3 April 1902, Vincent addressed the absence of fresh vegetables on the island and explained that it was “quite impossible to grow green food on the Island owing to the attacks made on gardens by the grey rats which were imported here about 8 months ago”. [Both Vincent and Hanitsch (1923) made reference to the introduced rats as being ‘grey’ or ‘slatey grey’ in colour. *R. rattus* is a notoriously variable species, and the genetic analyses of Wyatt *et al.* (2008) confirm that several of Durhams's rats trapped in 1901/02 were the black rat, *R. rattus*.] Allowing for a delay in the delivery of Vincent's letter from the Island to Singapore, it seems likely that “about 8 months ago” from the date of publication was around August 1901. This is 17 months later than the date he told Durham.

A devastating outbreak of disease on the Island put Vincent under great pressure from the colonial administration of the Straits Settlements in Singapore, casting some doubt on this later date. At that time, Christmas Island was experiencing a terrible epidemic of beriberi, which is caused by a dietary deficiency of the vitamin thiamine (B1). The disease was especially prevalent among the Chinese coolie workforce then working in the phosphate mines (Fig. 5). In the calendar year 1901, the worst year of the 1900–1904 epidemic, the death rate on Christmas Island was 475 per thousand among the Chinese coolies, in an average population of around 550 coolies. Eighty-six percent, or 220, of those coolie deaths were due to beriberi (see Hunt 2011 for an excellent account of this bleak period in the island's history). The outbreak on Christmas Island in predated the discovery of vitamins by more than a decade, and through the latter part of the 19th century there was debate over whether it was caused by dietary deficiency or germs (Carter 1977). However, it was widely known at the time of the Christmas Island outbreak that dietary reform could achieve spectacular successes in treating the illness. [Carter (1977) retells the case of a Japanese naval doctor who, by initiating massive dietary reform, reduced the incidence of beriberi among sailors from 40% to nil in just five years during the 1880s. These results were reported in European medical journals and reviewed in *The Lancet* in 1887. Durham himself was aware of the Japanese work – he made reference to it in the bibliography of another of his papers (Durham 1904).]

It seems that Captain Vincent bore the brunt of official and very public criticism for the lack of green vegetables on the island. Vincent's chief protagonist was Lewis Hare Clayton, a young, Cambridge-educated and Hokkien-speaking civil servant for the Straits Settlements (Fig. 6). Clayton visited the island in September 1900 and March 1901 to observe and report on the development of the



Figure 5. Beriberi broke out among the workforce on Christmas Island in 1900, and over several years this disease claimed hundreds of lives. In the early years of the epidemic, the state of the Island's supply of fresh food featured prominently in arguments between the Christmas Island Phosphate Company and the Colonial administration, publicly played out in the pages of *The Straits Times*. The Company Manager Captain Vincent blamed the introduced of black rats for the lack of leafy greens in the early years of the outbreak. This image of a beriberi patient suffering characteristic muscle wastage was taken by Dr William MacDougall between 1904 and 1908, and included in his PhD thesis of 1909 at the University of Edinburgh. Through careful experimentation, he devised a dietary regime that all but eliminated the disease on the Island. MacDougall arrived on the Island in April 1904 to witness the death knell of the native rats, which he observed dying on jungle paths. Hanitsch could not find any live rats just a few months later in September/October. Image reproduced with permission from Edinburgh University Library, Special Collections Department, Image ID 105344..

phosphate industry, and served as first resident District Officer from June 1901 until December 1902 (Hunt 2011). He was initially sympathetic to the challenges Vincent faced in setting up the mining operation in such a remote location, and reported favorably on Vincent's performance to September 1900 (Clayton 1901). Then, as the beriberi epidemic developed Clayton became a strident critic of both the Christmas Island Phosphate Company and its labour contractor Ong Sam Leong (see Hunt 2011). It was to a lengthy and highly critical report from Clayton to the Governor of the Straits Settlements, published in the *Government Gazette* on 7 March 1902 and précised in *The Straits Times* on 8 March, to which Vincent was responding with his letter published on 3 April. Clayton wrote that it "is not unreasonable to assume that the death-rate has been increased by the inadequacy of the water-supply, the total absence of fresh vegetables in the



Figure 6. Lewis Hare Clayton (far left) was a Straits Settlement official who was dogged advocate for the welfare of the mostly Chinese workforce on Christmas Island during the beriberi epidemic. He badgered the Christmas Island Phosphate Company to improve the state of the food and water supply on the island, and to improve housing and sanitation. Sir John Murray (far right) was the driving force behind the formation of the company, and first visited the Island in December 1900 when this photograph was taken. The relationship between the Colonial Administration and the Company was still amicable at this time; Clayton had just reported favourably on the Company's operations in general and on Captain Vincent's performance as manager, and beriberi had only just broken out. Relations were soon to deteriorate. From the collection of the National Archives of Australia (NAA R32/16 CIPC I Sheet 58).

*diet supplied to the coolies, the unsatisfactory nature of the hospital accommodation, and the long hours of work....The questions of water supply, diet and hospital accommodation have been repeatedly brought before the Company both by Government and also by their own medical advisers, but so far not much improvement has been effected, except in the case of the hospital which has been considerably enlarged". Although Clayton referred to the "Company", his criticism was clearly directed at Captain Vincent as Manager. The preamble that introduced the article in *The Straits Times* could only have added to Vincent's discomfort by implying that a ruthless profit motive overrode concerns for coolie welfare; "Mr Clayton's report.....is in many respects painful reading. From a financial point of view, no doubt, it is encouraging enough; but when one reads that this "Bonanza" costs over 475 lives per thousand per annum of the unfortunate Chinese coolies employed at the work, one pauses with horror in the perusal of the report."*

Given the very public scrutiny under which he was placed by the publication of Clayton's report in *The Straits Times*, Vincent clearly felt the need to defend himself and the Company. His letter of 3 April 1902 was a point-by-point response to Clayton's criticisms, and he argued the lack of greens on the island was due entirely to the effects of introduced rats. Claim and counter-claim had clearly not abated nearly a year later. Clayton again reported on the situation on Christmas Island

to the Legislative Council in Singapore on 3 February 1903, and again the tone was scathing. *The Straits Times* editorial said “Indeed from the report, which is official, it would seem that the company does little besides helping in the killing of the coolies and giving them bad water, and the miracle appears to be that any of them are now alive”. Vincent was already in Singapore in the week leading up to Clayton’s report, on his way home to England to have a dislocated elbow mended. He must have known what was in the offing, because he gave an interview to *The Straits Times*, published just two days after Clayton’s report was tabled, in which he explained more fully how he had encouraged the coolies to grow their own food at the Company’s expense, and when that failed, how he had stepped in personally to devise rat-proof fencing and how these efforts had been completely frustrated;

“...brave efforts have been made to construct a garden; but all such attempts have been failures. The rats get in and destroy the vegetables in spite of all precautions. Captain Vincent devised a rat-proof garden patch and laid it out, with great trouble and at great expense. It was surrounded with corrugated iron sunk deep in the ground and covered with rat-proof netting. The seedlings grown within that enclosure were obviously as safe from the predations of rats as they were from the ravages of barnacles, and the gallant Captain felt quite proud of his cleverness when he saw the little green sprouts boldly sticking forth an inch above the clay. Next morning when he went out to exhibit his seedlings they were not there. The rats had found a way in during the night and had stripped the enclosure of everything green.” This article did not specify which rat species was causing the problem. However, given this press interview was clearly intended to backstop his earlier letter of the previous April and to parry Clayton’s most recent barbs, Vincent was probably referring to the introduced *R. rattus*.

This very public spat allows for the possibility that rather than just muddling his dates, Captain Vincent was deliberately obfuscating to lessen his culpability for the deplorable death rate amongst the coolie workforce. Arguably, it would have been very much to Vincent’s advantage to report the introduction of the rats as relatively recent, because then he could (and did) claim the problem as too new for him to have found an effective solution. In fact, his rebuttal of 3 April 1902 placed the introduction of *R. rattus* to the Island at the very height of the beriberi epidemic. To further muddy the waters, Vincent was away in the United Kingdom during May–September 1901 (Clayton 1902b), so any report of the introduction of black rats in August would therefore have been second hand at best, probably from the Company Engineer and stand-in manager Mr Meek.

It cannot be known if Captain Vincent’s date of August 1901 was deliberate misinformation to protect himself and the company or not, in part because the little we know of him suggests that his loyalties were divided between the welfare of the workforce, and doing the bidding of his employers. Vincent was clearly sympathetic to the Chinese coolies – he had worked in the China trade for many years prior to his arrival on Christmas Island, he spoke Cantonese, and played the role of doctor with some compassion in the early days

of the beriberi epidemic, prior to the appointment of a qualified doctor (see Hunt 2011). Further, he chose to bear Clayton’s criticisms when technically, he wasn’t even responsible for the food supply – that had been the responsibility of the Singaporean businessman Ong Sam Leong since June 1899, when Ong was first contracted to supply labour to the mining operation. That he seemingly chose not to pass the buck to Ong suggests that Vincent felt a duty of care to the coolies. On the other hand, Hunt (2011) argues that Vincent probably succumbed to pressure from his Board of Directors not to spend money on improving coolie health through 1901, and worse, that he colluded with the visiting Managing Director Joseph Smithson to put 75 new coolies to work in the phosphate quarries. In doing so, the Company broke an agreement with the Government to have these men work towards ameliorating the shocking death rate by making improvements to the rudimentary hospital and the sanitary conditions around the coolie living quarters. Muddled dates or not, it was rather disingenuous of Vincent to blame the lack of fresh vegetables on introduced black rats. Annual reports by visiting civil servants for the decade preceding the beriberi outbreak regularly reported the endemic *Rattus macleari* as being troublesome to food production – one report even described this rat as “the devastator” (Leach 1897). It was not as if the problem with rats, endemic or alien, was a new one.

If Durham was aware of the inconsistency in Vincent’s dates for the arrival of *R. rattus*, he gave no indication of this in a series of unpublished reports to the London School of Tropical Medicine he wrote in February 1902, August 1902 and May 1903, nor his publication 1908 publication. However, he clearly wasn’t impressed by the Company’s efforts to grow fresh vegetables during the few months he was resident on the island from November 1901; “It may be said that no really serious attempt at gardening had been made up to the time of my visit. Complaints were made that the rats destroyed everything, but no steps were taken to prevent them. A few hundred yards of proper rat wiring & a little care seems all that is needed” (Durham 1902).

Did the *Hindoustan* introduce black rats to Christmas Island?

Although the research reported in this paper clarifies the name and date of arrival of the ship reported by Vincent to Durham, whether it was actually the *Hindoustan* that first introduced black rats to the Island is a separate issue, and one that may be impossible to resolve. Could there have been an earlier introduction of *R. rattus* that went undetected? An observation reported by Durham (1908) suggests this is well worth considering – he reported the black rats had “multiplied to very great numbers” by the time of his arrival in late November 1901, just over a year since the *Hindoustan* visited the previous year. Despite their legendary fecundity, this is possibly too short a period for black rats to have achieved this level of population growth, and Durham’s observation could be used to argue for an earlier introduction.

If so, then it was highly unlikely to have been before May 1898, when the naturalist C.W. Andrews completed his 10-month stay and left Christmas Island. Andrews lived at the tiny settlement at Flying Fish Cove, the only port at that time. He was clearly a careful observer, and made a point of stating in his monograph (1900) that ship rats had not yet reached the Island. If *R. rattus* was introduced earlier than Vincent reported, then in all likelihood it happened during the 28 months between Andrews' departure and the *Hindoustan*'s arrival. This can be narrowed down even further, based on the frequency of ships visiting the Island as reported in Australian and Singaporean newspapers and mentioned in Government Reports. I found only a single ship visiting the Island between May 1898 and April 1899, but 30 ships visited between April 1899 and the *Hindoustan*'s arrival in September 1900. This indicates that if rats had already reached the Island before the *Hindoustan*'s visit, then it was most likely they arrived during the preceding year. In the absence of other solid evidence, Captain Vincent's report of black rats being introduced to the island aboard the *Hindoustan*, which we now know was in September 1900, must be accepted at face value.

A revised timeline for the rapid extinction of the native rats

It took just a few short years for the blood-borne trypanosomes introduced with black rats to cause the extinction of Christmas Island's native rats (Table 2). In the currently accepted timeline, the period between introduction and extinction was 4 years and 9 months, spanning Captain Vincent's date of December 1899, until September–October 1904 when Karl Hanitsch of the Raffles Museum failed to find a single native rat (Pickering and Norris 1996; Wyatt *et al.* 2008). The evidence presented above suggests an even faster decline to extinction. Assuming the *Hindoustan* really did introduce *R. rattus* to Christmas Island in September 1900, then disease wiped out the immunologically naïve native rats in just four years.

The decline did not go unnoticed. Durham (1908) noted that “the large *Mus nativitatis* had already become so rare about the settlement at the time of my visits and I was unable to obtain either a freshly killed or a living specimen although a reward was offered”. Writing in 1923 of his 1904 expedition, Hanitsch recalled “The Inhabitants of the island had noticed the gradual disappearance of the Rodent (*R. macleari*), but were only too grateful for this dispensation needlessly to worry their heads about it”, probably a reference to their general nuisance value and the damage they caused to local gardens. Following his second visit to the Island in 1908, Andrews reported that the medical officer Dr McDougal (sic) told him “that some five or six years ago he frequently saw individuals of the native species of rats crawling about the paths in the daytime, apparently in a dying condition” (Andrews 1909). Dr William MacDougall (note correct spelling) didn't arrive on Christmas Island until April 1904 (Hunt 2011), making this the earliest possible date for his observations. The native rats were gone just six months later, and it seems that Dr MacDougall arrived

just in time to bear witness to the final stages of their extinction. The ecological fallout from the extinction of the endemic rats is unknown, but could be significant. Tidemann (1989) has speculated that *Rattus macleari* was a significant predator of the Island's endemic red land crab *Gecarcoidea natalis*, now famed for its abundance, massed annual breeding migrations and the role it plays in rainforest dynamics (Hicks *et al.* 1984, Hicks 1985, Green 1997, Green *et al.* 1997, Green *et al.* 1998, O'Dowd *et al.* 2003; Green *et al.* 2008, Green *et al.* 2011; Orchard 2012). Tidemann thinks their amazing numbers may be an artefact of the extinction of the rats (see also Flannery 1990, Meek 2000, Flannery and Schouten 2001).

Sir John Murray

In addition to Vincent, Durham, Clayton, MacDougall and Andrews, one other figure deserves special mention here. Sir John Murray (Fig. 7) was instrumental in founding the Christmas Island Phosphate Company in 1897, convinced that great riches were to be made from mining the Island's phosphate deposits. Murray was a geologist, and was for thirteen years until its final publication the chief scientific editor of the Challenger Report, the voluminous scientific analysis and reporting of the samples and records from the *Challenger* oceanographic expedition of 1872–1876. Murray himself was interested in the formation of coral reefs, and he was especially interested in the geology of oceanic islands. One of those was Christmas Island, and using his not inconsiderable connections, he arranged for the HMS *Flying Fish* to visit Christmas Island in 1887 to collect rock specimens. Murray noticed that one of the specimens collected on that visit contained a pebble of pure phosphate, and that planted a seed of commercial enterprise that came to fruition in the late 1890s when the first shipment of phosphate was taken off the Island (see Burstyn (1975) for an excellent description of the central role played by Murray in the establishment of the Christmas Island phosphate industry). Murray was well on the way to becoming a very rich man on the back of discoveries made from publicly funded research. Perhaps recognising his good fortune, Murray funded the 1897/98 expedition of Charles W. Andrews of the British Museum to visit the Island to document its intact condition before it was spoiled by the very phosphate mining industry that Murray had worked so hard to establish. In the *Introductory Note* to the Andrews' Monograph (1900), Murray wrote “It seemed highly desirable that this interesting island – which was evidently an upraised coral atoll – should be carefully examined and described by a competent naturalist and geologist, before being opened up by Europeans for agricultural and commercial purposes.... It has not hitherto been possible to watch carefully the immediate effects produced by the immigration of civilised man – and the animals and plants which follow in his wake – upon the physical conditions and upon the indigenous fauna and flora of an isolated oceanic island.” Murray's pessimism was realised more rapidly than perhaps he expected – he wrote this Note on 15 February 1900, and *R. rattus* was introduced to Christmas Island just seven months later in September.

Table 2. Revised timeline of the events leading up to, during and after the extinction of the native rats of Christmas Island.

Date	Event
May 1898	The naturalist C.W. Andrews of the British Museum leaves Christmas Island, having completed a comprehensive geological and biological survey of the Island. In his 1900 monograph, he reports that both endemic <i>Rattus</i> species, and the shrew, are all abundant and that <i>R. rattus</i> has not yet reached the island, although he thought this inevitable.
November 1899, April 1900 and May 1900	<i>SS Hindoustan</i> is recorded at Cape Town (South Africa), Buenos Aires (Argentina) and Beira (Mozambique), respectively. Given events on Christmas Island just a few months later, it is somewhat ironic that Portuguese authorities at Beira refuse to accept a cargo of cattle on the grounds they “were infected and in a dangerous condition and unfit to be landed”.
September 1900 (early)	<i>SS Hindoustan</i> arrives at Christmas Island and is photographed in Flying Fish Cove, probably by the company engineer Mr Meek. Captain Vincent observes ships rats being offloaded in a bale of hay; the founding population of <i>Rattus rattus</i> , its fleas and trypanosomes are introduced to Christmas Island. The shipment of phosphate taken off by the <i>Hindoustan</i> is listed by Clayton (1901) in his Annual Report for 1900, and the ship is later incorrectly named as the <i>Hindostan</i> in Clayton’s correspondence with the Colonial Secretary in Singapore in 1902.
September 1900 (late)	Clayton visits Christmas Island for five days, and reports that “beriberi has broken out”. There are 36 deaths between January and September, and a total of 62 for the year.
October 1900 (early)	<i>SS Hindoustan</i> is reported in the Straits of Hormuz, returning to Europe via the Suez Canal with 3300 tons of phosphate for delivery to Germany.
January – March 1901	The beriberi epidemic escalates, with 112 deaths in a population of 704. A further 127 men, mostly Chinese coolies, will die by the end of the year.
Nov 1901, 26 th	Dr Herbert Durham arrives on Christmas Island as part of the ‘Beriberi Expedition’ from the London School of Hygiene and Tropical Medicine, funded by the Christmas Island Phosphate Company.
December 1901 – March 1902	As part of his research on beriberi, Durham collects rats for a study of blood-borne disease, earliest specimen dated 16 December; latest dated 17 March. Vincent tells Durham that <i>Rattus rattus</i> was introduced on the <i>Hindoustan</i> , but Vincent misremembers the date of its arrival as Dec 1899. Durham reports this incorrect date in his 1908 publication, at the same time misspelling the name of the ship as the <i>Hindustan</i> . Durham later reports that <i>R. rattus</i> had ‘multiplied to very great numbers’ at this time.
March 1902, 8 th	Clayton’s scathing report of the mining operation on Christmas Island is précised in <i>The Straits Times</i> , placing Captain Vincent as manager under enormous pressure to address the terrible working conditions and appalling death rate on the island due to beriberi.
April 1902, 3 rd	Captain Vincent has a letter of rebuttal published in <i>The Straits Times</i> . In this letter he blames the lack of fresh green vegetables on the introduced rats, which he indicates were introduced to the island “about 8 months ago”, (i.e. around August 1901). Whether or not this is yet another innocent mistake or a deliberate ploy cannot be known.
January – February 1903	The war of words continues. Clayton tables another scathing report to the Legislative Council in Singapore (3 Feb), again making reference to the lack of fresh vegetables on the island. Again Vincent defends himself, this time by way of an interview published in <i>The Straits Times</i> on 5 Feb, but given in the days prior to the tabling of Clayton’s report. Vincent clearly knew what was coming, and used the opportunity of his trip through Singapore to make a pre-emptive strike.
April 1904	Dr William MacDougall arrives on the island, and through careful experimentation with the coolies’ diet, he drastically reduces the death toll due to beriberi. MacDougall’s observations of dying native rats, later published by C.W Andrews in 1909, obviously cannot have been made any earlier than April 1904.
October 1904, 17 th – 20 th	Richard Hanitsch and Henry Ridley traverse Christmas Island from Flying Fish Cove to Middle Point, on the south coast. Hanitsch later reports (1923) failing to see a single native rat, despite spending several nights camped in the forest, and despite coming to the island with the expressed intention of catching specimens. Later workers agree this marks the extinction of the native rats of Christmas Island.
August-September 1908	CW Andrews visits the Island and confirms the native rats as extinct. Like Durham, Andrews speculates that blood-borne disease introduced by black rats caused the extinctions.

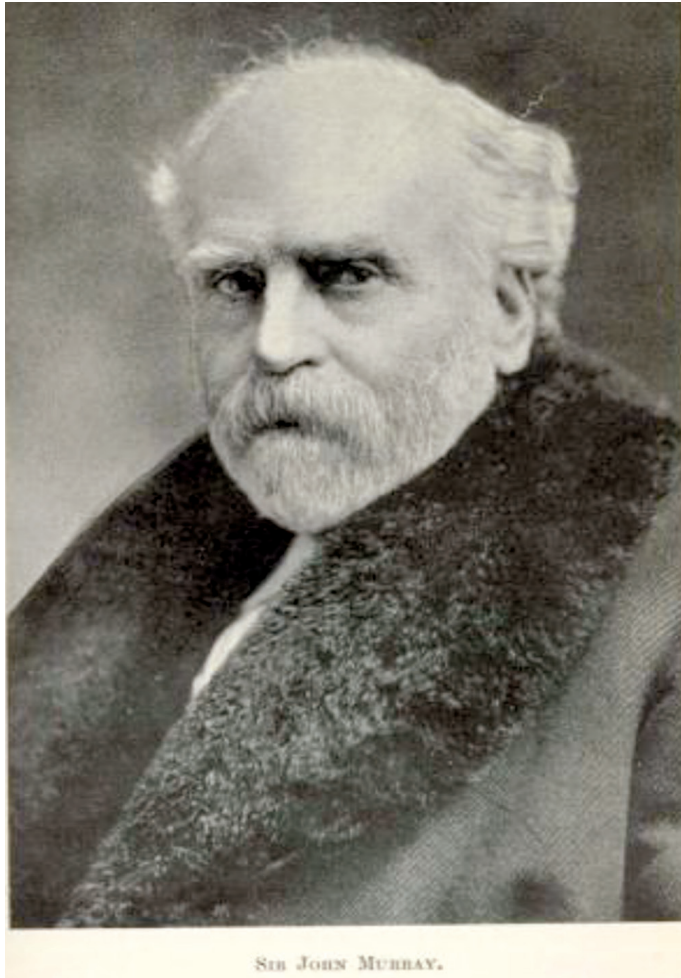


Figure 7. Sir John Murray, the scientist entrepreneur whose commercial exploitation of Christmas Island mineral resources facilitated a biological invasion that caused the extinction of one, and probably two, native endemic rats. Image originally published in Herdman, W.A. 1923. *Founders of Oceanography and Their Work: an Introduction to the Science of the Sea*. Edward Arnold & Co., London. Digitised image downloaded from the University of Washington Digital Collections, Freshwater and Marine Image Bank on 1 February 2013. http://content.lib.washington.edu/cdm4/item_viewer.php?CISOROOT=/fishimages&CISOPTR=36360&CISOBX=1&REC=7

Murray visited the Island twice, the first time for about a month in November-December 1900, and again in 1908. On the second trip, he invited the naturalist C.W. Andrews back to the Island so that Andrews could assess the impact of the mining operation on the island's biota a decade after his first trip. This was the trip on which Andrews received the report from Dr MacDougall about his observations of the dying native rats in 1904, confirmed their extinction, and like Durham (1908), attributed their demise to disease imported by black rats. It is easy to imagine the kind of conversations these learned scientific men may have had about the social, economic and biological impacts of the mining operation. One cannot help but wonder if Murray, as originator of the phosphate mining industry on Christmas Island, felt any sense of responsibility for the loss of the native rats.

Conclusion

Two key details of the currently accepted and widely reported version of the story describing the introduction of black rats to Christmas Island need revision. The historical record – a more than century old photograph of ship at Christmas Island, shipping intelligence from newspapers in Australia, Singapore, the United Kingdom and the United States, and official correspondence between the District Officer on Christmas Island and his superiors in Singapore – all point not to the *SS Hindustan* visiting in December 1899, but to the *SS Hindustan* visiting in September 1900. While the incorrect spelling of the ship's name is obviously a simple error, Vincent's conflicting dates are harder to explain. There is no obvious reason to see his date of December 1899 as anything besides a simple mistake, because he likely discussed the introduction of the black rats with Durham when he (Durham) began collecting them in December 1901, before the beriberi epidemic had put Vincent under pressure from the colonial administration in Singapore. Vincent himself drew the introduction of black rats into a bitter and very public dispute with his letter to *The Straits Times* in April 1902, when he reported a second, later date of August 1901 for the introduction of black rats. Whether or not this was yet another innocent mistake, or a deliberate ploy, cannot be known.

This paper was born of the chance discovery of an old photograph in the Melbourne offices of the National Archives, showing a tramp steamer at Christmas Island. In one sense, this photograph is unremarkable – it is just one of many in the National Archives showing ships moored at Flying Fish Cove in the very early days of phosphate mining, and the *Hindustan* was just one of thousands of tramp steamers then plying their trade on the world's oceans. On the other hand, it is a remarkable photograph, because in all likelihood it captures forever the very instant when an invasive species and its parasites were introduced to a remote oceanic island, thence to cause the extinction of at least one, and probably two endemic species.

There is a sadly ironic footnote to this story. A lengthy newspaper article published in the *The Times* (London) on 7 November 1901 described a complicated court case in which a shipping company was attempting to recover payment from the British South Africa Company (BSAC) for two cargoes of live bullocks, mealies, oats, hay and bran. The cargoes had been loaded on two ships at Buenos Aires in April 1900 for delivery to the BSAC at Beira in Mozambique, but in May the Portuguese authorities there turned away one of the vessels on the grounds that the cattle "were infected and in a dangerous condition and unfit to be landed". Little did anyone know that in just a few months hence, the *SS Hindustan* would deliver another kind of infectious and dangerous cargo that would very quickly cause the extinction of the endemic rats of Christmas Island.

Acknowledgments

I thank Ted Finch, Mori Flapan and several subscribers to the Mariners_L Listserver for answering my calls for help. Ted and Mori independently confirmed that the SS *Hindustan* and SS *Hindoustan* were in fact different ships, and provided information of their specifications and history of ownership. Mori found the photograph of the SS *Hindustan* loading coal at New Castle in Fig. 1. Emma Golding at the London School of Hygiene and

Tropical Medicine provided access to Herbert Durham's unpublished expedition reports and correspondence. John Hunt commented on an earlier draft of this ms, and shared with me his discovery of Clayton's correspondence on the "*Hindustan*" phosphate shipment of September 1900. This led me to reconsider Captain Vincent's original date of December 1899. John Woinarski also made valuable comments on an earlier draft.

References

- Andrews, C.W.** 1900. *A Monograph of Christmas Island (Indian Ocean)*. Published by the Trustees of British Museum (Natural History), London.
- Andrews, C.W.** 1909. An account of a visit to Christmas Island. *Proceedings of the Zoological Society* 1909: 101-103.
- Aplin, K.P.** 2008. Maclear's Rat, *Rattus macleari*. Pp 693-694 in *The Mammals of Australia*, 3rd Edition edited by S. Van Dyck and R. Strahan. Reed New Holland, Sydney.
- Burstyn, H.L.** 1975. Science pays off: Sir John Murray and the Christmas Island Phosphate Industry 1886-1914. *Social Studies of Science* 5: 5-34. <http://dx.doi.org/10.1177/030631277500500102>
- Cairns-Wicks, R.** 2004. *Nesiota elliptica*. In: IUCN 2011. IUCN Red List of Threatened Species. Version 2012.2. www.iucnredlist.org. Accessed on 19 June 2012.
- Carter, K.C.** 1977. The germ theory, beriberi, and the deficiency theory of disease. *Medical History* 21: 119-136. <http://dx.doi.org/10.1017/S0025727300037662>
- Clayton, L.H.** 1901. Colonial Report No. 319, Christmas Island. Report for 1900. Presented to both Houses of Parliament April 1901.
- Clayton, L.H.** 1902a. Correspondence dated 25 March 1902, entitled Christmas Island Royalty. National Archives of the United Kingdom, CO 273/279, Straits 22842.
- Clayton, L.H.** 1902b. Correspondence from Lewis Clayton on Christmas Island to the Colonial Secretary, Straits Settlements dated 4 June 1902. Reprinted in a bound volume of letters between Clayton as the District Officer on Christmas Island, the Colonial Secretary in Singapore, and the Christmas Island Phosphate Company entitled "Correspondence with the Christmas Island Phosphate Company, Limited, regarding the carrying out of certain necessary sanitary improvements", p. 6. Paper no. 36 of 1902, laid before the Legislative Council in Singapore. National Archives of Australia MP1171/1, Barcode 923541, Item N.
- Durham, H.E.** 1902-3. Investigation in Beriberi on Christmas Island – Durham's Reports. Unpublished manuscripts in the archives of the London School of Hygiene and Tropical Medicine, Ref GB 0809 Durham.
- Durham, H.E.** 1904. Notes on beriberi in the Malay Peninsula and on Christmas Island (Indian Ocean). *Journal of Hygiene* 14: 112-155.
- Durham, H.E.** 1908. Notes on Nagana and on some haematozoa observed during my travels. *Parasitology* 1: 227-235.
- Flannery, T.F.** 1990. The rats of Christmas past. *Australian Natural History* 23: 394-400.
- Flannery, T.F. and Schouten, P.** 2001. *A Gap in Nature: Discovering the World's Extinct Animals*. Text Publishing, Melbourne.
- Green, P.T.** 1997. Red crabs in rain forest on Christmas Island, Indian Ocean: activity patterns, density and biomass. *Journal of Tropical Ecology* 13: 17-38. <http://dx.doi.org/10.1017/S0266467400010221>
- Green, P.T., Claussen, J. and O'Dowd, D.J.** 2010. Lost for a century: rediscovery of the endemic Ridley's jewel orchid, *Zeuxine exilis* Ridl. (Orchidaceae), on Christmas Island, Indian Ocean. *Gardens Bulletin Singapore* 61: 319-326.
- Green, P.T., Lake, P.S. and O'Dowd, D.J.** 1999. Monopolization of litter processing by a dominant land crab on a tropical oceanic island. *Oecologia* 119: 435-444. <http://dx.doi.org/10.1007/s004420050805>
- Green, P.T., O'Dowd, D.J. and Lake, P.S.** 1997. Control of seedling recruitment by land crabs in rain forest on a remote oceanic island. *Ecology* 78: 2474-2486. <http://dx.doi.org/10.2307/2265907>
- Green, P.T., O'Dowd, D.J. and Lake, P.S.** 2008. Recruitment dynamics in a rainforest seedling community: context-independent impact of a keystone consumer. *Oecologia* 156: 373-385. <http://dx.doi.org/10.1007/s00442-008-0992-3>
- Green, P.T., O'Dowd, D.J., Abbott, K.L., Jeffery, M., Retallick, K. and Mac Nally, R.** 2011. Invasional meltdown: invader-invader mutualism facilitates a secondary invasion. *Ecology* 92: 1758-1768. <http://dx.doi.org/10.1890/11-0050.1>
- Hanitsch, K.R.** 1923. *A Visit to Christmas Island*. Unpublished manuscript, Oxford University Museum Archives, Oxford.
- Hicks, J.W.** 1985. The breeding behaviour and migrations of the terrestrial crab *Gecarcoidea natalis* (Decapoda: Brachyura). *Australian Journal of Zoology* 33: 127-142. <http://dx.doi.org/10.1071/ZO9850127>
- Hicks, J.W., Rumpff, H. and Yorkston, H.D.** 1984. *Christmas Crabs*. 1st edition. Christmas Island Natural History Association, Christmas Island.
- Hulme, P.E.** 2011. Addressing the threat to biodiversity from botanic gardens. *Trends in Ecology and Evolution* 26: 168-173. <http://dx.doi.org/10.1016/j.tree.2011.01.005>
- Hunt, J.G.** 2011. *Suffering Through Strength: the Men who made Christmas Island*. Published by the author, Canberra.
- Johnson, C.** 2007. *Australia's Mammal Extinctions: a 50,000-year History*. Cambridge University Press, Melbourne.
- Keyser, A.** 1897. Papers Relating to the Cocos-Keeling and Christmas Islands, Serial No. 17, Enclosure 1, Presented to both Houses of Parliament March 1897.
- Lamoreux, J.** 2009. *Rattus macleari*. In: IUCN 2011. IUCN Red List of Threatened Species. Version 2012.2. www.iucnredlist.org. Accessed on 26 October 2012.
- Leach, J.** 1897. Colonial Report No. 216, Christmas Island. Report for 1897. Presented to both Houses of Parliament November 1897.

- Low, T. 1999. *Feral Future*. Penguin, Australia.
- Lunney, D., Law, B., Schulz, M and Pennay, M. 2011. Turning the spotlight onto the conservation of Australia bats and the extinction of the Christmas Island Pipistrelle. Pp 485–498 in *The Biology and Conservation of Australasian Bats*, edited by B. Law, P. Eby, D. Lunney, and L. Lumsden. Royal Zoological Society of NSW, Mosman, NSW, Australia. <http://dx.doi.org/10.7882/FS.2011.048>
- Meek, P.D. 2000. The decline and current status of the Christmas Island Shrew *Crocidura attenuata trichura* on Christmas Island, Indian Ocean. *Australian Mammalogy* 22, 43-49. <http://dx.doi.org/10.1071/AM00043>
- Mihalca, A.D., Gherman, C.M. and Cozma, V. 2011. Coendangered hard-ticks: threatened or threatening? *Parasites and Vectors* 4, Doi:10.1186/1756-3305-4-71. <http://dx.doi.org/10.1186/1756-3305-4-71>
- Musser, G.G. and Carleton, M.D. 2005. Superfamily Muroidea. Pp 894-1531 in *Mammal Species of the World: a Geographic and Taxonomic Reference*, edited by D.E. Wilson and D.A. Reeder. The John Hopkins University Press, Baltimore, USA.
- Myers, K., Parer, I., Wood, D., and Cooke B.D. 2003. The rabbit in Australia. Pp. 108–157 in *The European Rabbit: the History and Biology of a Successful Colonizer*, edited by H.V. Thompson and C.M. King. Oxford University Press, Oxford, United Kingdom.
- O'Dowd, D.J., Green, P.T. and Lake, P.S. 2003. Invasional 'meltdown' on an oceanic island. *Ecology Letters* 6: 812-817. <http://dx.doi.org/10.1046/j.1461-0248.2003.00512.x>
- Orchard, M. 2012. *Crabs of Christmas Island*. Christmas Island Natural History Association, Christmas Island.
- Paddle, R. 2000. *The Last Tasmanian Tiger: the History and Extinction of the Thylacine*. Cambridge University Press, Melbourne.
- Pickering, J. and Norris C.A. 1996. New evidence concerning the extinction of the endemic murid *Rattus macleari* from Christmas Island, Indian Ocean. *Australian Mammalogy* 19: 19-25.
- Ritvo, H. 2012. Going forth and multiplying: animal acclimatization and invasion. *Environmental History* 17: 404-414.
- Skerratt, L.F., Berger, L., Speare, R., Cashins, S., McDonald, K.R., Phillott, A.D. et al. 2007. Spread of chytridiomycosis has caused the rapid global decline and extinction of frogs. *EcoHealth* 4: 125-134. <http://dx.doi.org/10.1007/s10393-007-0093-5>
- Tidemann, C.R. 1989. Survey of the terrestrial mammals on Christmas Island (Indian Ocean). Unpublished report to Australian National Parks and Wildlife Service. (Australian National University, Canberra.)
- Townsend, C.R. 1996. Invasion biology and ecological impacts of brown trout *Salmo trutta* in New Zealand. *Biological Conservation* 78: 13-22. [http://dx.doi.org/10.1016/0006-3207\(96\)00014-6](http://dx.doi.org/10.1016/0006-3207(96)00014-6)
- Wyatt, K.B., Campos, P.E., Thomas, M., Gilbert, P., Kolokotronis, S.-O., Hynes, W.H., DeSalle, R., Daszak, P., MacPhee, D.E. and Greenwood, A.D. 2008. Historical mammal extinction on Christmas Island (Indian Ocean) correlates with introduced infectious disease. *PLoS One* 3, e3602. doi:10.1371/journal.pone.0003602 <http://dx.doi.org/10.1371/journal.pone.0003602>